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Brain and Cognition 56 (2004) 189–197
Brain and Cognition
www.elsevier.com/locate/b&c

Error-related psychophysiology and negative affect☆

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Accepted 14 November 2003
Available online 3 September 2004

Abstract

The error-related negativity (ERN/Ne) and error positivity (Pe) have been associated with error detection and response monitoring. More recently, heart rate (HR) and skin conductance (SC) have also been shown to be sensitive to the internal detection of errors. An enhanced ERN has consistently been observed in anxious subjects and there is some suggestion that the ERN is related to general negative affective experience (NA). The ERN has been source localized to the anterior cingulate cortex—a structure implicated in the regulation of affective, response selection, and autonomic resources. Thus, the findings that autonomic measures and affective distress are related to response monitoring are consistent with anterior cingulate cortex function. In the present experiment, we sought to evaluate more comprehensively the relationship between self-reported negative affect and error-related physiology in a between-groups design. Results indicate that high NA was associated with significantly greater ERN and error-related SCR, and smaller Pe. These results are discussed in terms of anterior cingulate cortex function, psychopathology, and response monitoring.
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Keywords: NA, Negative Affect; ERN; ERP; Response monitoring; HR; SCR

1. Introduction

The error-related negativity (ERN or Ne) is a response-locked event-related brain potential (ERP) observed at fronto-central (Fz, FCz, Cz) recording sites that begins around the time of an erroneous response, and peaks 50–100 ms later (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; Gehring, Coles, Meyer, & Donchin, 1990; Gehring, Goss, Coles, Meyer, & Donchin, 1993). The ERN has been observed across a variety of stimulus and response modalities, and appears to reflect the activity of a generic response-monitoring system (Bernstein, Scheffers, & Coles, 1995; Falkenstein et al., 1991; Holroyd, Dien, & Coles, 1998; Van 't Ent & Apkarian, 1999). In terms of the source of the ERN, studies utilizing source localization have consistently found that error-related brain activity can be best described by a neural generator in the anterior cingulate cortex (Dehaene, Posner, & Tucker, 1994; Holroyd et al., 1998).

Numerous studies have found that the ERN is also sensitive to motivational and contextual factors. For instance, increased focus on accuracy over speed has been found to increase the magnitude of the ERN; similarly, the ERN appears larger when subjects are more certain that they have made a mistake—suggesting that the response-monitoring system is sensitive to motivational factors during performance (Falkenstein et al., 2000; Gehring et al., 1993).

Individual differences in anxiety have also been found to influence the ERN. Specifically, Gehring, Himle, and Nisenson (2000) found that patients with obsessive-compulsive disorder (OCD) have significantly larger ERNs than age-matched control subjects (for similar results

☆ Portions of this paper were presented both at the 43rd annual meeting of the Society for Psychophysiological Research, Chicago, IL, October, 2003 and at Errors, Conflict, and the Brain: Current Opinions on Performance Monitoring, Dortmund, July, 2003.

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0278-2626/$ - see front matter © 2004 Elsevier Inc. All rights reserved.
doi:10.1016/j.bandc.2003.11.001

in patients with OCD, see Johannes et al., 2001). In studies from our own laboratory, we have likewise reported enhanced error-related brain activity in obsessive-compulsive and worried undergraduates when compared to both control subjects and subjects with specific phobias (Hajcak & Simons, 2002; Hajcak, McDonald, & Simons, 2003b).

These results, linking anxiety to enhanced response monitoring, are consistent with both anxious behavior and the pathophysiology of anxiety. Specifically, OCD and pathological worry have been shown to relate to increased doubts about actions and concerns over mistakes (Frost & Steketee, 1997; Hajcak & Huppert, 2004; Stober & Joormann, 2001). Furthermore, the anterior cingulate cortex has been shown to be hyperactive in many anxiety disorders and this has led some researchers to postulate that anterior cingulate cortex dysfunction may be related to the experience of symptoms common to all anxiety disorders (Kimbrell et al., 1999; Malizia, 1999).

In addition to individual differences in anxiety, an increased ERN-like component to negative feedback has also been found in subjects diagnosed with clinical depression (Tucker, Luu, Frishkoff, Quiring, & Poulsen, 2003). In considering the substantial symptom overlap and diagnostic comorbidity between anxiety and depression, Clark and Watson (1991) proposed that both disorders are characterized by high levels of affective distress, or negative affect (NA). In terms of the differentiation between anxiety and depression, the tripartite model suggests that only depression is characterized by low levels of positive affect (PA), whereas anxiety is uniquely characterized by physiological hyperarousal (Clark & Watson, 1991; for empirical support, see Brown, Chorpita, & Barlow, 1998). Within this framework, it is possible that an enhanced ERN is not a function of either anxiety or depression specifically, but relate to the underlying high NA characteristic of both syndromes.

Some support for this possibility was reported by Luu, Collins, and Tucker (2000), who found significant correlations between NA and ERN amplitude in college students. That is, ERNs were enhanced in college students who were high on self-reported NA. High-NA students in the Luu et al. study, however, had larger ERNs only in the first testing quartile; in fact, the relationship between NA and ERN was in the opposite direction for the remaining three quartiles. Luu et al. interpret this result in terms of task disengagement over time in the high-NA students despite their initial higher than normal concerns with performance. Because the task-disengagement explanation was based solely on an increased reduction in post-error slowing across time in the high-NA group and was not accompanied by any change in performance (e.g., errors or RT), the relationship between ERN and negative affect must be regarded as theoretically plausible, but not well substantiated at this point.

Far less studied than the ERN, the error positivity (Pe) is an ERP component that also appears to be related to response monitoring processes. The Pe has a slightly more posterior scalp distribution, and follows the ERN—peaking approximately 200–400 ms after subjects make a mistake (Falkenstein et al., 2000; Hohnsbein, Falkenstein, & Hoormann, 1989; Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001). Falkenstein et al. (2000) suggested that the Pe may index processing that occurs after error detection, such as error recognition or error salience. This possibility was supported by a Nieuwenhuis et al. (2001) study, which reported a relationship between Pe and the subjective awareness of making a mistake. Nieuwenhuis et al. found that when subjects were unaware of their mistakes the ERN was unaffected, but the Pe was substantially reduced. In the several studies that have related ERN to differences in affective variables such as anxiety, there have been no formal evaluations of the anxiety variable and its impact on the Pe. Visual inspection of the relevant data suggests either no differences in Pe (Hajcak et al., 2003b; Luu et al., 2000) or smaller Pe in high-anxious subjects (Gehring et al., 2000; Hajcak & Simons, 2002).

In addition to the ERN-Pe ERP complex, a number of recent studies have reported that autonomic nervous system (ANS) activity is also sensitive to response monitoring. For instance, Somsen, Van der Molen, Jennings, and van Beek (2000) found that cardiac deceleration was related to negative feedback in a Wisconsin card sorting task; similar data relating HR deceleration to negative feedback during response monitoring has also been reported by Crone et al. (2003). Finally, data from our own lab indicates that both HR and SCR are also sensitive to endogenous error detection (Hajcak, McDonald, & Simons, 2003a). Like the Pe, these ANS responses to errors have not been evaluated with respect to individual differences in anxiety or NA.

The present study was conducted to more comprehensively evaluate the relationship between self-reported affective experiences and error-related psychophysiology in a between-groups design. The primary aim was to compare the ERN, Pe and ANS responses from subjects that were either high or low in self-reported NA. A secondary aim was to compare the same variables in subgroups of high-NA subjects with different levels of positive affect (PA). All subjects were selected on the basis of the NA and PA subscales of the Positive and Negative Affect Scale (PANAS; Watson, Clark, & Tellegen, 1988). To this end, we measured ERPs and ANS activity while subjects performed a speeded reaction time task in which they had to respond to Stroop stimuli. In particular, subjects saw color words (e.g., "red") presented in either a congruent (red) or incongruent (blue) color;

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